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A Study of Some Thermoelastic Analysis of Functionally Graded Materials and it's Applications

Research proposal submitted
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Submitted by

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Ph.D. Synopsis

"A Study of Some Thermoelastic Analysis of Functionally Graded Materials and it's Applications"

1. Introduction:

Thermoelasticity is a fascinating branch of physics that explores the simultaneous effects of thermal and mechanical fields in an elastic body. It delves into predicting the thermomechanical behavior of materials. Essentially, it's an advancement of elasticity theory that incorporates thermal effects like thermal stress, strain, and deformation. Thermal deformation refers to the tendency of a material to change its mechanical properties as the temperature varies. Consequently, thermoelasticity theory predicts the thermomechanical interactions in an elastic body.

It's worth mentioning that Duhamel [1], who formulated thermal stresses, was the first to speculate on the coupling between thermal and mechanical fields. He derived equations for the strain in an elastic body with temperature gradients. Later, Neumann [2] obtained similar results. However, the theory treated thermal and mechanical effects as independent factors, determining total strain by superimposing elastic strain and thermal expansion caused by temperature distribution alone. Hence, this theory does not account for the interactions between strain and temperature distributions in a specified manner. In 1857, Thomson [3] incorporated thermodynamic arguments and became the first to use the laws of thermodynamics to determine the stresses and strains in an elastic body in response to varying temperatures. However, the field of coupled thermoelasticity was significantly advanced by the pioneering work of Biot [5]. In his work, Biot used the fundamental principles and laws of thermomechanics—including the conservation of mass and energy, the balance of momentum, and kinematic relations—to derive the basic governing equations and constitutive relations for coupled thermoelasticity. This work laid the foundation for what is now known as the classical coupled (or conventional) thermoelasticity theory. Additionally, Biot introduced the variational principle within this context, which is instrumental in deriving Lagrangian equations. He also developed methods for obtaining general solutions to thermoelasticity equations in an isotropic, homogeneous medium.

Origin of the research problem:

In 1837, Duhamel and Neumann introduced the theory of uncoupled thermoelasticity. In 1956, Biot has developed the coupled theory of thermoelasticity. This theory couples the equations of elasticity and heat conduction, addressing the primary flaw in the uncoupled theory. In [5], Nowacki's thermoelastic model is employed, which implies infinite speeds of propagation for thermoelastic waves.

In the 1980s, Functionally Graded Materials (FGMs) were first proposed by Japanese scholars [6]. They were originally designed to address the significant temperature difference caused by the overheating of the outer surface of spacecraft while maintaining a stable internal temperature. FGMs combine the best properties of different materials to achieve superior performance. Once introduced, this concept sparked worldwide exploration and expanded into many fields such as metal-ceramic, metal-polymer, and ceramic-polymer combinations. Generally, FGMs exhibit regular gradient changes on both macro and micro scales, including uniform and layered variations. As a result, FGMs possess a range of desirable physical and chemical properties.

The term functionally graded materials contain two important words functionally and graded. The word functionally modifies graded. Refer to simple functional materials but and graded materials. The general concept of functionally graded materials is materials with graded functions inside them. Functionally graded materials are abbreviated as FGMs hereafter. Original FGMs are one-body materials in which their thermal expansion coefficient is changed gradually between the front and back sides. This is achieved by changing their composition from metallic to ceramic.

The purpose of Functionally Graded Materials (FGMs) is to mitigate internal thermal stress at elevated temperatures. FGMs have wide-ranging applications in fields such as aerospace, automobiles, industry, defense, energy, electronics, electrical engineering, biomedical sciences, and sports. Their popularity stems from their gradual variation in composition and structure over volume, which results in varied chemical, thermal, electrical, and mechanical properties. These materials can be tailored for specific applications and functions. In FGMs, material properties are not homogeneous across the entire material.

2. Review of Literature and Development in the subject:

Functionally Graded Materials (FGMs) are advanced materials engineered to exhibit a gradual variation in composition and structure over their volume, resulting in corresponding changes in their mechanical, thermal, or other properties. This unique characteristic makes FGMs pivotal for applications requiring tailored performance and functionality. This review explores the historical development, key research trends, and current advancements in the field of FGMs.

In 2011, Liew et al. [7] presented a review of various meshless methods for the analysis of laminated composite and FGM plates and shells. In 2013, Jha et al. [8] provided a detailed review of the history of FGMs and various homogenization models for these materials, focusing on the thermal-based analysis of FGM structures. In 2015, Swaminathan et al. [9] conducted a comprehensive review of static, free vibration, and buckling analysis of FGM plates. Swaminathan and Sangeetha [10] continued this work in 2017 with a thorough review of the thermal-based analysis of FGM structures. In 2018, Sayyad and Ghugal [11] reviewed the analysis of sandwich FGM beams. That same year, Birman and Kardomatea [12] provided a brief overview of the methods and theories available for analyzing sandwich structures. In 2019, Zhang et al. [13] reviewed the buckling, bending, and free vibration analysis of FG structures. Garg and Chalak [14] conducted a detailed review in 2019 of the analysis of sandwich structures under hygrothermal conditions. In 2020, Ghatage et al. [15] published an extensive review on the modeling and analysis of multi-directional FGM plates. More recently, marking 30 years since the invention and application of FGMs, Saleh et al. [16] offered insights into the manufacturing design, applications, and challenges of FGMs.

3. Objective of research/Proposed Hypothesis:

The main objectives of this study are

To study different properties of FGM materials.

1. Try to work on different types or examples of FGM 's.
2. Try to analyses different FGM's models which are currently used in different areas.
3. To study applications related to Aerospace, medicine, defense, Commercial and Industrial, Biotechnology etc.

4. Methodology to be adopted:

1. Initially, for the review purpose relevant research papers, review articles, books, journals, etc. will be collected the through internet and various institutions.
2. To participate in conferences, seminars, workshops.
3. To obtain alternative solution of the problem by applying new technique and compare our result with obtained already results.
4. To use computational software viz. Maple Mathematica, Mathcad, MATLAB etc.
5. The carried research work will be published in the well reputed journals.

5. Importance of study /society applications:

Interdisciplinary Relevance:

The issue has great importance because it is an interdisciplinary work related with the branch science and technology like physics, Mechanical Engineering and Civil Engineering etc. the isotropic and anisotropic thermoelastic problems to be considered have important industrial applications.
Some of the applications of functionally graded materials are highlighted below:

1. **Aerospace**: – Functionally graded materials can withstand very high thermal gradient, this makes it suitable for use in structures and space plane body, rocket engine component etc. If processing technique is improved, FGM are promising and can be used in wider areas of aerospace.

2. **Medicine**: – Living tissues like bones and teeth are characterized as functionally graded material from nature to replace these tissues, a compatible material is needed that will serve the purpose of the original bio-tissue. The ideal candidate for this application is functionally graded material. FGM has find wide range of application in dental and orthopedic applications for teeth and bone replacement.

3. **Defense**: – One of the most important characteristics of functionally graded material is the ability to inhibit crack propagation. This property makes it useful in Défense application, as a penetration resistant material used for armor plates and bullet-proof vests.

4. **Energy**: – FGM are used in energy conversion devices. They also provide thermal barrier and are used as protective coating on turbine blades in gas turbine engine [17].

5.**Optoelectronics**: – FGM also finds its application in optoelectronics as

graded refractive index materials and in audio-video discs magnetic storage media. Other areas of application are: cutting tool insert coating, automobile engine components, nuclear reactor components, turbine blade, heat exchanger Tribology sensors, fire retardant doors, etc]. The list is endless and more application is springing up as the processing technology, cost of production and properties of FMG improve [18,19].

Current and futuristic applications of FGM are listed as follows-

1. **Commercial and Industrial**: - Pressure vessels, Fuel tanks, Cutting tool inserts, Laptop cases, Wind turbine blades, Firefighting air bottles, MRI scanner cryogenic tubes, Eyeglass frames, Musical instruments, Drilling motor shaft, X-ray tables, Helmets.
2. **Automobiles**: - (SiC-SiC) Combustion chambers, (AISiC) Engine cylinder liners, (SiCw/AI-alloy) Diesel engine pistons, (E-glass/epoxy) Leaf springs, (AI-C) Drive shafts, (AI-SiC) Flywheels, Racing car brakes, (SiCp/AI-alloy) Shock absorbers.
3. Aerospace equipment and structures: - (TiAl-SiC fibers) Rocket nozzle, Heat exchange panels, Spacecraft truss structure, Reflectors, Solar panels. Camera housing, Turbine wheels (operating above 40,000 rpm), Nose caps and leading edge of missiles and Space shuttle.
4. **Sub-marine**: - (Carbon and glass fibers) Propulsion shaft, (Graphite/Epoxy) Cylindrical pressure hull, (Glass/Epoxy) Sonar domes, Composite piping system, (AI- SiC) diving cylinders.
5. **Biotechnology**: - The functional gradient nano hydroxyapatite reinforced polyvinyl alcohol (nano HA/PVA) gel bio composites can be prepared through a layer-by-layer casting method combining with freeze/thaw cycles technology. Nano HA/PVA gel bio composites have been a promising and excellent artificial particular cartilage repair material. Compared to hydrogel-based materials such as poly (vinyl alcohol) (PVA), poly (lactic acid) and chitosan, nano HA/PVA gel bio composites possess superior bioactivity and mechanical properties because of the nano HA existence in the composites.

International and National Status:

National and international researchers have carried out plenty of research work on thermoelasticity and FGM. The works of few amongst them are quoted in the direct and indirect problems. (Refer origin of the research problem). Many scientists and researchers many more contributed in the development of

functionally graded materials like M. sasaki et al. [21] he tried to design and prepare SiC/C Functionally Gradient Material (FGM) accompanying compositional gradient from SiC to C, for developing thermal-barrier materials for space plane., Kawasaki *et al.* [21] he worked on development of functionally graded materials via power metallurgy, A.Ş. Demirkıran [23] worked on evaluation of functionally gradient coatings produced by plasma-spray technique. Christopher P Shaw, [24] reported properties of a new type of pyroelectric ceramic structure containing a layer of known porosity laminated between two dense layers, to form a functionally gradient material (FGM), Huang C S. [25], discussed accurate first-of-its-kind solutions of the free vibration characteristics of side-cracked rectangular functionally graded material (FGM) thick plates are reported., Li Xin, [26] studied functionally gradient materials are continuous in their physical and chemical properties, such as composition, texture, density and elastic modulus.

National Status:

Indians have contributed in the development of thermoelasticity and functionally graded materials. We have prominent examples like Mahamood R. M [27], who presented an overview on FGM and he also highlighted various fabrication methods with solid freeform providing the best advantage over other processes because of the manufacturing flexibility it offers, Gaikwad and Naner et al. [29] worked on the analysis of transient thermoelastic temperature distribution of a thin circular plate and its thermal deflection under uniform heat generation. Gaikwad and P. Ghadle et.al [28] have worked on to determine the quasi-static thermal stresses of an infinitely long circular cylinder having constant initial temperature under steady-state field. Experimental study on tribological behaviour of aluminium–copper functionally graded material. Advancements and Challenges in Additively Manufactured Functionally Graded Materials [29].

Significance of the study:

The thermoelastic problems have many applications in the field of functionally graded materials. Large number of engineering components and tools require materials performance varying with location.

- The body of a gear must be tough, whereas it's surface must be hard and wear resistant.
- A knife needs only to be hard as its cutting edge; elsewhere, the

material must be strong and tough.

Many of the most demanding current applications of materials fall under this category.

6. Proposed work plan/Formulation & Structure of Study:

Year-Wise plan of work and targets to be achieved:

First year:

i) To collect the references in relevant field.

ii) To study the references in relevant field.

iii) To attend the seminars/Conferences/Workshops on relevant topic.

Second year:

i) To attend the seminars/Conferences/Workshops on relevant topic.

ii) To formulate new thermoelastic problems on different solid.

iii) To study existing and new technique which will be applied on these problems.

iv) To construct the mathematical models for various solid and study their thermoelasticity.

v) To cheek whether these models are practically feasible or not, these will be discussed with engineering researchers.

Third year:

i) To study applications of obtained results

ii) To publish the work in the reputed journals.

iii) To submit the work to the authority.

Date :13/12/2024

Mr. Krishna B. Kadam

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Date :13/12/2024

Dr. Kishor R. Gaikwad

(Research Guide)

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